A Method for Acquisition of Visual Environment Data in the Range of Daylight

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ABSTRACT: The assessment of the visual environment is a difficult, yet necessary task for the evaluation of the built environment. In order to predict the usability of daylight, the quality as well as the quantity of daylight has to be considered.

The present paper introduces a new methodology for capturing the visual environment. It is based in the use of digital cameras and neutral density filters combined to register the complete range of luminance present in daylight. The use of fish-eye lens adapters permits the acquisition of data in a whole hemisphere, which makes it a suitable method for the evaluation of visual comfort conditions. The results show good correspondence with luminance and illuminance measurements. The inclusion of the data in the Radiance software permits its use in more elaborate simulations; therefore some possible applications are demonstrated.

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INTRODUCTION

In order to compare different built environments and the occupant’s responses to those environments, a correct characterization of the visual conditions is necessary. This is mostly obtained from luminance and illuminance data.

Calibrated CCD cameras have already been used to obtain accurate luminance values throughout a digital image at one time. With the popularisation of digital cameras, CCD sensors of fair quality became available at lower prices. Furthermore, the development of self-calibration software, allowing a simple yet precise method to determine luminance response, makes this a fast and inexpensive method to assess visual environments.

For the present work, a Nikon Coolpix 5000 camera was utilized. This camera permits the use of a fish-eye lens adapter covering a view angle of approximately 183 degrees, making it suitable for different needs like visual comfort studies. The software Photosphere was used to calibrate the luminance response of the CCD and obtain high dynamic range images.

Furthermore, the possibility of including these environments in lighting simulations permits the assessment of different design variations, occupant’s position, etc.

2. HIGH DYNAMIC RANGE

The range of luminance information that can be obtained from a single digital image is limited. This is usually seen as over- or under-exposition. In order to register a wider range, several exposures of the same scene are necessary. Each exposure records a limited range and then all are combined to obtain the complete scene (Figures 1 and 2).

Figure 1: Two sample images taken with high and low exposures.

Figure 2: High dynamic range image composed from the data of the above two images. It has been filtered to reduce the contrast (in this example, the sun is out of range).
The range of luminance present in daylit scenes can be very high. Sun’s luminance at noon can be as much as $2 \times 10^9 \text{ cd/m}^2$. Given the limitations in speed and aperture controls of the camera, neutral density filters are also necessary. In this study, three cameras were used, two of them using filter combinations with transmittances of 0.3% and 0.001% respectively (Figure 3).

![Figure 3: Ranges recorded with each exposure combination.](image)

The storage of luminance data requires also high dynamic range formats. Most common image file formats, using 8 bit per pixel, allow the record of a limited dynamic range. Special file formats, like the Tiff LogLuv, or the Radiance file format, use 32 bit per pixel, allowing much higher dynamic ranges. The Radiance file format, for example, allows values between $10^{-38}$ and $10^{38}$ with a relative accuracy of 1% [2].

3. CAMERA CALIBRATION

Two kinds of calibration are necessary in order to ensure correct values: camera’s luminance response and geometry of the fish-eye image.

3.1 Luminance response calibration

The software Photosphere [3] was used. It implements a self-calibration algorithm that permits the calculation of the luminance response curve for a given camera. This relates the image output (pixel value) to the luminance input, and is characteristic of each camera-lens combination.

The software uses redundant information from the different images in order to calculate the luminance response, allowing the measurement of luminance values out of digital images.

With this calibration, the software produces high dynamic range images, combining the information of several exposures (Figure 4).

![Figure 4: Composition of a high dynamic range image from multiple exposures.](image)

3.2 Lens calibration

It is necessary in order to obtain the relation between incident angle and the corresponding position in the image, thus permitting the reconstruction of the environment from image data (Figure 5).

Several measurements were taken with different targets. The lens was found to follow the equiangular model, with minor deviations.

![Figure 5: Relation between incident angle and position in the image.](image)

4. USE OF DATA IN SIMULATIONS

4.1 Synthetic vs. real sky definitions

One of the major limitations of daylight simulations is the representation of sky conditions. There are several sky models that predict the luminance distribution according to weather conditions and location. These models however, do not consider small variations, specially in partially clouded skies, that can be important when studying visual comfort, contrast levels, etc.

The luminance data recorded with the method described above can be included in lighting simulations to illuminate a scene as if it were inside the same environment. This method, called image based lighting (IBL) [1] has been developed to produce more realistic renderings (Figures 6 and 7). When combined with calibrated high dynamic range images, it can also produce numerically consistent values that can be used in daylighting research.

Additionally, images rendered using IBL also account for exterior obstacles like trees or other buildings that can be difficult to simulate digitally.

The software associates each direction in space with the luminance value recorded in the images.
Therefore, in the simulations, the environment behaves as if it were placed at infinite distance. Since the images are recorded from one particular viewpoint, care should be taken to avoid parallax problems.

The software used in the present study was Radiance v.3.5 [4].

**Figure 6:** Basic principle of image based lighting. The luminance data is used to illuminate a scene.

**Figure 7:** Example of image based lighting simulation.

**Table I:** Validation of simulated results. Measured vs. simulated illuminance.

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**4.2 Validation of results**

In order to validate the numerical results from IBL simulations, the luminance values recorded from images were used to calculate the illuminance in the simulated environment. The result was then compared to illuminance measurements taken in situ. This way, not only specific values were tested, but the integration of all the values in one hemisphere. The results show good correspondence (Table 1).

**4.3 Example of application**

Simulations using image based lighting can be very useful in a number of applications. Of especial interest is its use in comfort conditions and glare assessment, which require the measurement of luminance values in the visual field.

The combination of real environment measurements with numerical simulations can be used to predict the behavior of different design decisions, or renovations in an existing building. Figures 8, 9 and 10 show the simulation of an interior environment and two variations of the window design. The exterior environment is the same as in figure 7.

**Figure 8:** Example of interior environment simulation.

**Figure 9:** Variation, adding a reflective light-shelf.
CONCLUSION

A method for recording the visual environment has been presented. This method permits the study of the qualitative and quantitative conditions of a given environment. Care should be taken that the calibration of the camera is correct and provides reliable results.

Recording the complete range of daylight can be more problematic in that it requires the use of (at least) three cameras combined with neutral density filters. However, this allows its use in any possible situation and, in simulations, to replace synthetic generated skies with more accurate ones.

The inclusion of measured environments in lighting simulations permits more specific applications. Some possible uses of this technique have been demonstrated. One major advantage is that exterior obstructions are also included, if care is taken that they are not placed relatively close to the scene, generating parallax problems.

Measuring luminance values in the whole visual field at one moment permits the study of visual comfort conditions in real situations, as opposed to controlled laboratory settings. At present, this methodology is being implemented to study visual comfort in buildings, under operating conditions.

REFERENCES


